CP Measurements with B_s Decays to Charm

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We report the study of $B^- \to D^0K^-$ decays, where the D^0 is reconstructed in flavor $(K^-\pi^+)$ or CP-even $(K^-K^+, \pi^-\pi^+)$ eigenstates. We report the measurement of the ratio $R = \frac{BR(B^-\to D^0_{flav}K^-)}{BR(B^-\to D^0_{flav}\pi^-)}$ as $0.065 \pm 0.007(stat) \pm 0.004(syst)$. We also report the first observation of the decay $B^0_s \to D_s^+D_s^-$ and the measurement of the ratio $R = \frac{BR(B_s\to D_s^+D_s^-)}{BR(B^0\to D_s^+D^-)}$ as $1.67 \pm 0.41(stat) \pm 0.12(syst) \pm 0.24(f_s/f_d) \pm 0.39(Br_{\phi\pi})$.

I. INTRODUCTION

The Collider Detector at Fermilab (CDF) began to collect Run-II data in 2001 from the collisions of proton and anti-proton at an energy $\sqrt{s} = 1.96$ TeV. Since then CDF has collected data of total integrated luminosity of about 2 fb^{-1}. The data is enriched with all types of B-species making CDF the ideal place for studying B-physics.

CDF-II detector [1] is a multipurpose axially symmetric spectrometer which includes high resolution tracking system providing a very good momentum resolution. The tracking system is further aided by the Silicon Vertex (SVX-II) detector providing excellent secondary vertex resolution and enabling to identify heavy flavor B-decays. CDF is also capable of identifying hadron species using, dE/dx information from the drift chamber (COT), and the Time of Flight (ToF) detector.

The large $b\bar{b}$ cross section at CDF is an advantage to study B-physics. However, due to proportionally large (10^3) inelastic cross section, the data have to be collected using specialized triggers. The data used for the analysis presented here were collected using two displaced track (B hadronic) triggers. The trigger requirements include having at least two tracks with an impact parameter larger than 120 micron with respect to the primary vertex.

We report the study of $B^- \to D^0K^-$ decays, as a first step towards the effort leading to the measurement of the CKM angle, γ. We also report the observation of $B_s \to D_sD_s$ decay mode and the measurement of the ratio of the branching fractions with respect to $B^0 \to D_s^+D^-$ decay mode.

II. MEASUREMENT OF CKM ANGLE, γ

The detrmination of the CKM angles provide important checks on the consistency of the Standard Model. The partial widths of the $B^- \to D^0K^-$ decays provide a theoretically clean way of measuring the CKM angle, $\gamma = arg(V_{ud}V^\star_{ub}/V_{cd}V^\star_{cb})$. There are several methods based on the D^0 decay mode used to extract the CKM angle, γ:

- The GLW (Gronau, London and Wyler) Method [2, 3] uses $D^0_{flav} \to K^-\pi^+$, $D^0_{CP+} \to K^-K^+, \pi^-\pi^+$ and $D^0_{CP-} \to K^0_s\pi^0, K^0_s\phi, K^0_s\omega$ decays.
- The ADS (Atwood, Dunietz and Soni) method [4, 5] uses $D^0_{flav} \to K^-\pi^+$ and the double cabibbo suppressed $D^0_{dcs} \to K^+\pi-$ decays.
- The Dalitz method [6] uses $D^0_{flav} \to K^0_s\pi^+\pi^-$ decay.

The advantage is that these methods do not require tagging or time-dependent measurements. The CKM angle, γ has been measured using Dalitz method [7, 8]. Using the GLW method the parameters needed for the γ measurement are:

$$R = \frac{BR(B \to D^0_{flav}K)}{BR(B \to D^0_{flav}\pi)} \tag{1}$$

$$R_+ = \frac{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)}{BR(B^- \to D^0_{CP+}\pi-) + BR(B^+ \to D^0_{CP+}\pi^+)}$$

$$A_{CP+} = \frac{BR(B^- \to D^0_{CP+}K^-) - BR(B^+ \to D^0_{CP+}K^+)}{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)}$$

where A_{CP+} and $R_{CP+} = R_+/R$ are related to the angle, γ, the magnitude r of the ratio of the amplitudes for the processes $B^- \to \bar{D}^0K^-$ and $B^- \to D^0K^-$, and the relative strong phase δ between these two amplitudes, through the relations $R_{CP+} = 1 + r^2 + 2r\ \cos\delta\ \cos\gamma$ and $A_{CP+} = 2r\ \sin\delta\ \sin\gamma/R_{CP+}$.

The CDF has analyzed 360 pb^{-1} data and measured the ratio, R, given by equation 1 as a first step towards the measurement of the CKM angle, γ using the GLW method [9]. The B^- candidate is reconstructed by adding another track with pion mass hypothesis to the D^0 candidate. The selection requirements include having an isolated B candidate with a quality cut on B vertex which has to be significantly displaced from the primary

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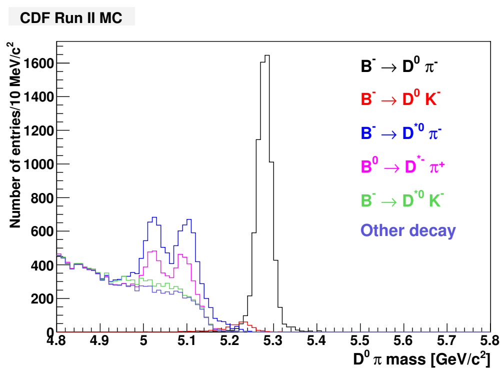

FIG. 1: Invariant mass distribution of different B decay modes obtained from Monte Carlo simulation.

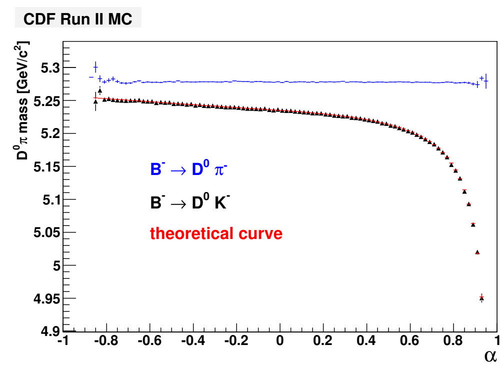

FIG. 2: Distribution of the invariant mass of the $D^0\pi$ Vs momentum imbalance, α.

vertex. The invariant mass distribution of the B^- candidates obtained from Monte Carlo events is shown in figure 1. As shown in figure 1, the principal physics background in the signal mass region is $B^- \to D^{0\star}\pi^-$.

To measure the ratio R, an unbinned maximum likelihood fit is performed which combines the kinematics and PID (dE/dx) information of the event. The fit is performed in a mass window [5.17-5.60] GeV to reject other physics backgrounds in the low mass region. The variables used in the fit are:

- $M_{D^0\pi}$, the invariant mass of B candidates with pion mass hypothesis applied to track coming from B.
- The momentum imbalance, α defined as:

$$\begin{aligned} \alpha &= \quad 1 - p_{trk}/p_{D^0} \qquad \text{if} \quad p_{trk} < p_{D^0} \\ &= -(1 - p_{trk}/p_{D^0}) \quad \text{if} \quad p_{trk} \geq p_{D^0} \end{aligned} \tag{2}$$

  which provides good separation between $B^- \to D^0\pi^-$ and $B^- \to D^0K^-$ decay modes as can be seen from figure 2 obtained from simulated events.
- Total momentum of the B: $p_{tot} = p_{trk} + p_{D^0}$
- PID information (dE/dx) of the track coming from the B.

Figure 3 shows the invariant mass distribution obtained from CDF data with the fit projections superimposed. The fit returns 3265 $\pm$ 38 $D^0\pi$ and 224 $\pm$ 22 D^0K events. We measured the ratio R as

$$R = \frac{BR(B \to D^0_{flav}K)}{BR(B \to D^0_{flav}\pi)} = 0.065{\pm}0.007\,(stat){\pm}0.004\,(syst)$$

We also have signal from the D_{CP} modes: about 380 candidates from the $B^- \to D_{CP}\pi^- \to [K^+K^-]\pi^-$ and about 100 candidates from $B^- \to D_{CP}\pi^- \to [\pi^+\pi^-]\pi^-$ decays.

Another interesting channel that permits a very clean measurement of the CKM angle, γ is the $B_s \to D_sK$ decay modes. Final states of both sign, $B_s \to D_s^{\pm}K^{\mp}$ and $\bar{B}_s \to D_s^{\mp}K^{\pm}$, are accessible by both the B_s mesons

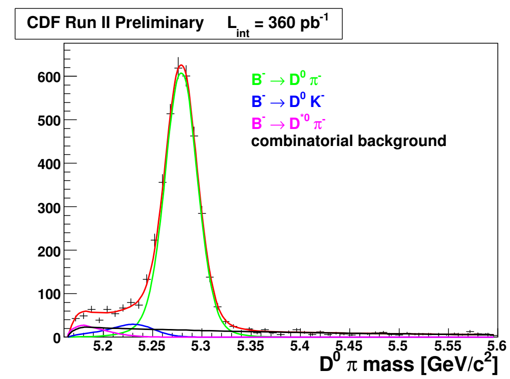

FIG. 3: The invariant mass distribution of B candidates obtained from CDF data with fit projections superimposed.

with similar sized amplitude (λ^3). B_s oscillation then causes the amplitudes to interfere. In this case, a time dependent CP asymmetry measurement is needed. CDF expects to see about 200 D_sK candidates in 1 fb^{-1} data.

III. RESULTS FROM THE $B_s \to D_s^+D_s^-$ DECAY MODE

While the measurement of the mass difference Δm_s between the mass eigenstates in the $B_s - \bar{B}_s$ system at CDF [10] provides important knowledge about CKM matrix parameters, the measurement of the relative width difference $\Delta\Gamma/\Gamma$ would reveal additional information and give a complementary insight into the CKM matrix. The CP-even eigenstate is expected to decay faster than the CP-odd due to the $\bar{b} \to \bar{c}c\bar{s}$ quark level transition being predominantly CP-even. The biggest contribution to the difference between the states is coming from the $B_s \to D_s^{(\star)}D_s^{(\star)}$. While the $B_s \to D_s^+D_s^-$ has a pure CP-even final state, the $B_s \to D_s^{(\star)}D_s^{(\star)}$ has predominantly CP-even final state. By measuring the $BR(B_s \to D_s^{(\star)}D_s^{(\star)})$, it is possible to measure $\Delta\Gamma/\Gamma$ [11]:

$$2BR(B_s \to D_s^{(\star)}D_s^{(\star)}) \approx \frac{\Delta\Gamma_{CP}}{\Gamma} \tag{3}$$

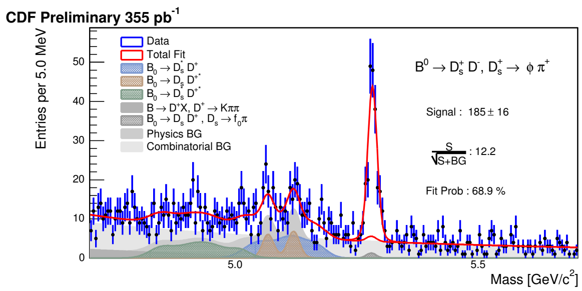

FIG. 4: The invariant mass distribution of the $B^0 \to D_s^+ D^-$ decay mode obtained from CDF data with fitted curves superimposed.

where $\Delta\Gamma_{CP} = \Delta\Gamma_s/\cos\phi$. It is also possible to use the $BR(B_s \to D_s^{(\star)} D_s^{(\star)})$ to measure the CKM angle, γ [12]. We report here, the first observation of $B_s^0 \to D_s^+ D_s^-$ decay modes and the measurement of the ratio of the branching fractions $R = \frac{BR(B_s \to D_s^+ D_s^-)}{BR(B^0 \to D_s^+ D^-)}$ using 360 pb^{-1} CDF data [13].

The events were reconstructed from the bottom to the top in the decay chain. The selection requirements include significantly displaced B vertex. The selection cuts were optimized by maximizing the significance of the signal with respect to the combinatorial background. The events were reconstructed in multiple D_s decay modes ($D_s \to \phi\pi$, $K^\star K$ and 3π) to have more statistics. To determine the event yields, the reconstructed invariant mass is fitted using templates obtained from Monte Carlo simulation for the physics backgrounds and float only the fractions keeping the shape fixed.

Figure 4 shows the invariant mass distribution of the normalization decay mode $B^0 \to D_s^+ D^-$ where $D_s^+ \to \phi\pi^+$. The yields are: 183 ($\phi\pi$), 128 ($K^\star K$) and 84 (3π). As can be seen from the figure 4 that in low mass region many physics backgrounds appear due to the incomplete or incorrect reconstruction of the decays similar to signal in mass, decay content and topology.

The signal decay mode $B_s \to D_s^+ D_s^-$ is reconstructed such that one D_s decays as $D_s \to \phi\pi$ and other decays to $D_s \to \phi\pi$, $K^\star K$ and 3π modes. In figure 5, the invariant mass distribution for $B_s \to D_s^+ D_s^-$ decay is shown where both D_s decays to $D_s \to \phi\pi$ modes. A total of about 9 signal candidates are observed in the data in this decay mode as obtained from the fit. To obtain the significance of the observation, we fit the background with the flat shape omitting the signal region and calculate the probability of fluctuation inside signal region to observe the signal level. Using only $B_s \to D_s^+ D_s^-$ $(\phi\pi)(\phi\pi)$ decay mode, the significance of signal observation is 5.8σ; summing all other decay modes ($K^\star K$ mode 6 candidates and 3π mode 8 candidates) would make the observation more obvious.

To determine the ratio, R, we combine the yields from all three channels and use the relative reconstruction efficiency obtained from Monte Carlo along with the PDG values of branching ratios. We obtain the ratio as,

$$
\begin{aligned}
R &= \frac{BR(B_s \to D_s^+ D_s^-)}{BR(B^0 \to D_s^+ D^-)} \\
&= 1.67 \pm 0.41(stat) \pm 0.12(syst) \pm 0.24(f_s/f_d) \pm 0.39(Br_{\phi\pi})
\end{aligned}
$$

the error is dominated by the statistics and the uncertainty in $D_s \to \phi\pi$ branching fraction.

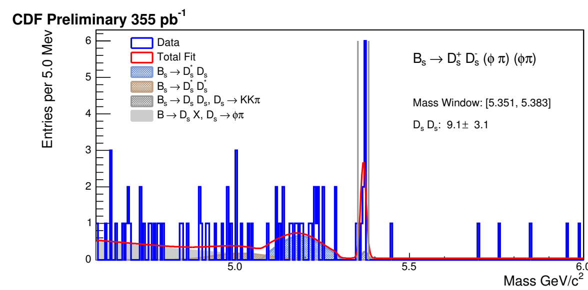

FIG. 5: The invariant mass distribution of the $B_s \to D_s^+ D_s^-$ decay mode. The templates used in the fit for $D_s^\star D_s$ and $D_s^\star D_s^\star$ decays are obtained from MC.

IV. CONCLUSION

As a first step towards the measurement of the CKM angle, γ, we have studied the $B^- \to D^0 K^-$ decay mode and measured the ratio of branching fractions with respect to $B^- \to D^0\pi^-$ mode . We have also observed $B_s^0 \to D_s^+ D_s^-$ decay and measured the ratio of branching fractions with respect to $B^0 \to D_s^+ D^-$ decay. CDF is updating these analysis with larger data sample.

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